# Next-generation EUV Lithography: challenges and opportunities

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## Introduction

Shrinking the wavelength with maintaining or increasing throughput is a traditional way to enable improved imaging and increasing depth of focus for the last 20 years. Transition from 13.5 nm to a shorter wavelength offers an opportunity to combine high imaging capabilities with still managing the process window. Changing the working wavelength will introduce a modification to a number of subsystems of the lithographer including light source and imaging optics. Our work is aiming at investigation of the potential of shorter wavelength lithography system performance and challenges associated with switching to a shorter wavelength. Here we report on the status of the ongoing research on key elements of an optical lithography system at λ=6.7 nm including source efficiency, multilayer coating and projection optics design.

## Opportunities:

- 6.x nm can provide matching DOF at lower CD than 13.5 nm lithography
- Imaging at smaller nodes in single exposure. At $k_1$=0.3, λ=6.7 nm:
  - NA=0.3: CD=7 nm
  - NA=0.4: CD=5 nm

$$DOF \sim \frac{\lambda}{NA^2}$$

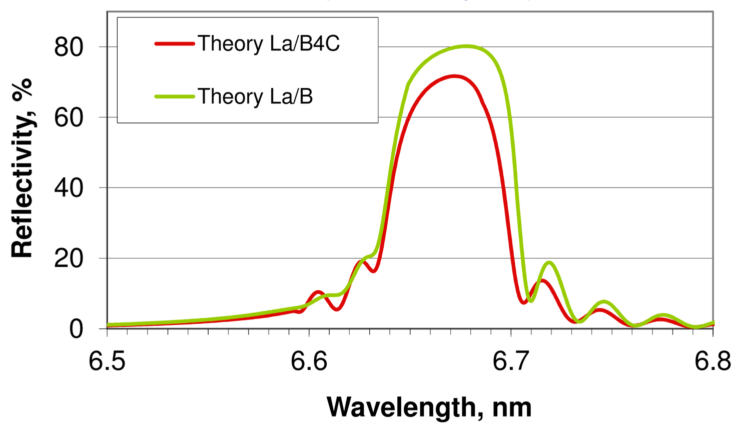
$$CD = k_1 \cdot \frac{\lambda}{NA}$$

## Impact of decreasing wavelength on a EUV lithography system

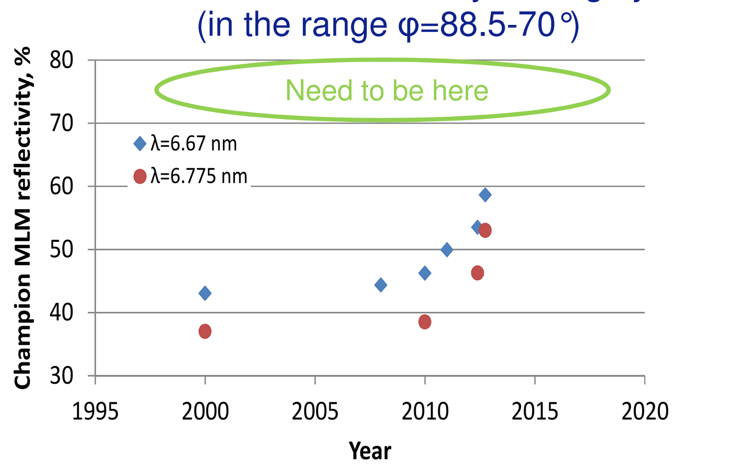
- **Imaging**
  - Flare level scales ∝$1/\lambda^2$
  - Bandwidth of the optical column $\Delta\lambda_\Sigma/\lambda$=2% for Mo/S → $\Delta\lambda_\Sigma/\lambda$=0.6% for La/B; (or $\Delta\lambda_\Sigma/\lambda$=0.4% for La/$B_4$C)
  - 3D effects on reticle: transmission of 30 nm TaN absorber $T_{13.5}$=11%; $T_{6.7}$=19%
- **MLM Technology**
  - Smaller layer thickness ∝ λ → layers ~1.6 nm
  - Requirements to interlayer diffusion ∝ λ → σ<0.3 nm interface
  - More bi-layers: @13.5 nm N=40 → @6.7 nm N~150-200
- **Source**
  - New fuel is needed with the matching CE (3-5%) in the narrow bandwidth → currently Gd at λ=6.775 nm is considered
- **Resist**
  - 6.7nm(186eV) photons vs 13.5nm(92eV) photons → Potential shot noise increase
  - Quantum efficiency of current EUV resist will decrease due to ~6x lower absorption of conventional carbon based resists → new resist material choice is required

## Multilayer coatings

Theoretical reflectivity of 1 MLM (200 bi-layers)



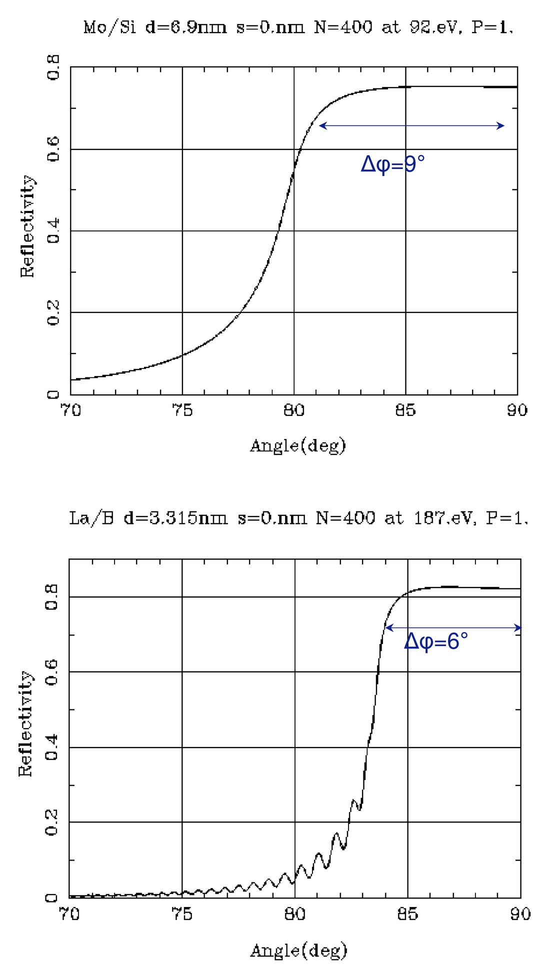

Demonstrated ML reflectivity through years (in the range φ=88.5-70°)



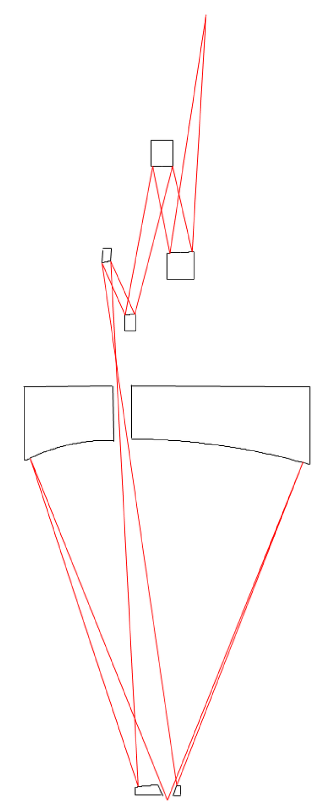

- Number of techniques identified leading to increasing MLM reflectivity (see papers 1-3)
- Achieved reflectivity is improved in last years (40% to 58%) but yet far form 70+%

1) Igor A. Makhotkin, Proc. SPIE, Vol. 8322, (2012)
2) Yuri Platonov, et al. Osmic inc. (2001) (see also CXRO database)
3) N.N. Salashchenko, et al. Tech. Phys. Volume 55, Issue 8, pp 1168-1174 (2010)
4) V. Banine et al., International Symposium on EUVL (2012)

## New design of projection optics required



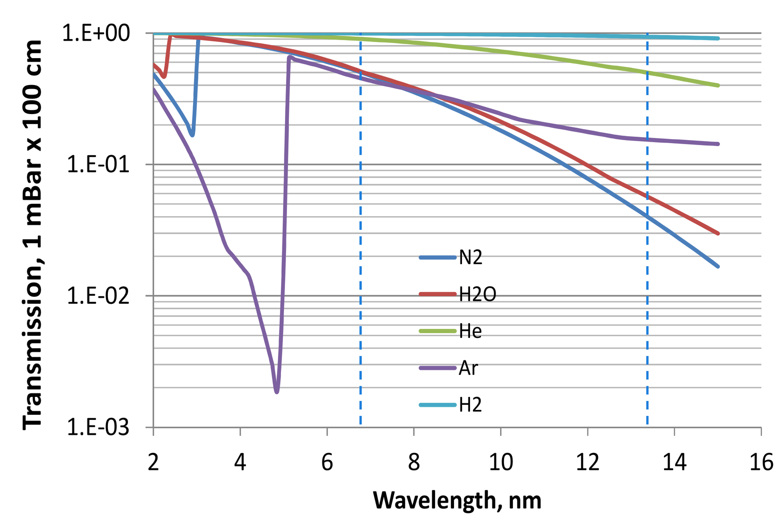

Example of a possible new design with NA=0.35



La/B MLM has ~1.5x lower angular band than Mo/Si MLM:

- Impact on POB design -> smaller angle variation possible over the mirror
- Source, illuminator mirror losses are acceptable
- Lower mask reflectance for angles Δφ>6° → **Reflectivity decreases by <2x for NA<0.6**

## Transmission of common gases at BEUV wavelengths




6.x nm radiation shows quite low absorption in:

- Gas environment
- Contamination layers

Integral improvement up to **1.3x** is feasible

## Source CE and matching to ML coatincs

- Two elements are identified as fuel candidates with bright transitions around 6.x nm:
  - Tb with peak emission at λ=6.5 nm
  - Gd with peak emission at λ=6.775 nm
- Based on model of RZLINE* (Gd and Tb) in band CE for 6.7 nm is ~2x lower than that for 13.5 nm
- Up to now in the experiments with flat target it seems to be true
- Max achieved CE=1.8% (vs 4-5% for 13.5 nm)

Measured CE data for Gd at 6.775 nm in 0.6% band for various conditions (Single shot!)

| Target geometry | | CO2 (70 ns) | YAG (40 ns) | YAG (2 ns) |
|---|---|---|---|---|
| Flat | % | 0.9 | 0.1 | 0.9 |
| 3D mesh | | ? | 0.1 | 0.6 |
| Alloy | | 0.5 | 0.3 | 0.4 |
| Colloid | | 1 | 0.3 | ? |
| Perforated foil | | 1.8 | ? | ? |

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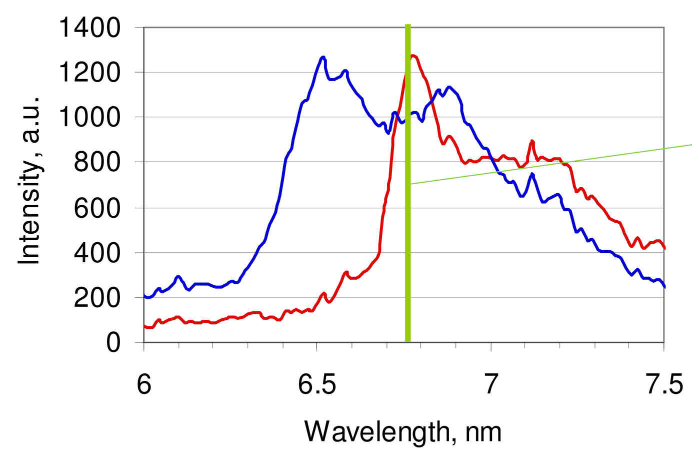
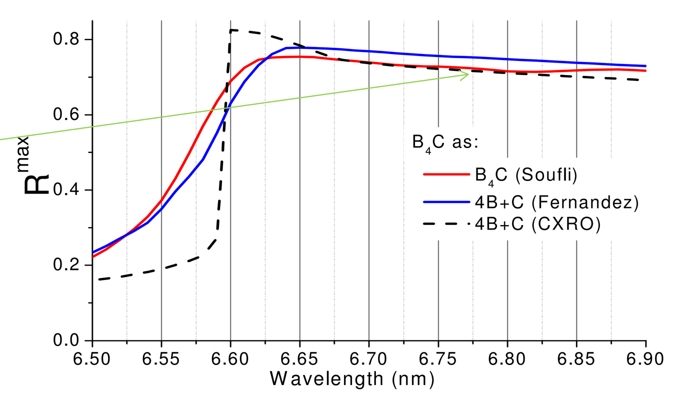
LPP emission spectra of Gd and Tb




Peak reflectance spectrum of 1 La/$B_4$C MLM




From I. Makhotkin, et al. Proc. of SPIE 8322 - 38 V.2 (2012)

- Optical constants of B close to the absorption edge at 6.6 nm are debated. Optimum wavelength for throughput $\lambda_{opt}$=6.6-6.65 nm
- Tb and Gd provide comparable CE at $\lambda_{Tb}$=6.5 nm; $\lambda_{Gd}$=6.775 nm. Peaks are shifted with respect to optimum of La/B optics
- Gd is widely available cheap material (unlike Tb) → λ=6.775 nm is preferred
- Large uncertainty exists w.r.t. reflectivity of La/$B_4$C around 6.7 nm, eg for Gd maximum:
  - Based on CXRO n,k: mismatch of the wavelength might cause 3x total optical thrpt loss, while
  - Based on n,k measurement by R. Soufli: it is **1.3-1.5x**

## Throughput comparison 13.5 and 6.x systems

Theoretical CE 1:2 for 6.x and 13.5

↓

Theoretical Optical throughput 3x (for LaB) & 1x (La$B_4$C) for 6.x vs 13.5 nm

↓

Additional optics losses 1.5-3x for 6.x vs 13.5 nm

↓

Vacuum environment transmission 1.3x for 6.x vs 13.5 nm

↓

For the same throughput ~1x-5x** more power input into the source is needed

* Resist sensitivity is taken comparable  ** Uncertainty in ML performance is very high

## Summary and Conclusions

- If chose among other wavelengths for a next step after 13.5 nm 6.x nm is the most promising
- To become a viable option for lithography a number of challenges for 6.x nm has to show a rapid improvement:
  - ML coating
    - Though ML has a potential of for high peak reflectivity (up to 80%) for La/B but,
    - Currently demonstrated reflectivity La$B_4$C is 58.6% @70 deg and has to become scalable yet to ~70+% (the small bandwidth of ML will not allow to reach this peak reflectivity in real optical systems)
  - EUV source
    - Theoretically CE for 6.x nm is ~2x lower to that of 13.5 nm,
    - Single shot CE 1.8% has been demonstrated
    - Scalability to the real source value still to be proven
    - 1x-5x more power input is needed to match the overall throughput losses
  - Actual available bandwidth limits the overall transmission of optics. Thus new optical designs to account for the small bandwidth are needed
  - Optimization of EUV source spectrum with ML optics is required
  - Extendibility of resist to 6.x nm has to be proven

This work is the result of hard work and dedication of teams at ASML, Zeiss and many technology partners worldwide.
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